AIRCRAFT SYSTEMS ENGINEEERING

LIFECYCLE CONSIDERATIONS

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What is the lifecycle of an Aircraft ?

- 20 years? 30 years?
- What is the lifecycle of a typical automobile? (10 years? 15 years?)
- How about a ship? (aircraft carrier? Battleship “New Jersey” launched in 1943 was used in Viet Nam in 1971
- Approx.1500 DC-3 aircraft still flying!

Weapon System Life Cycles

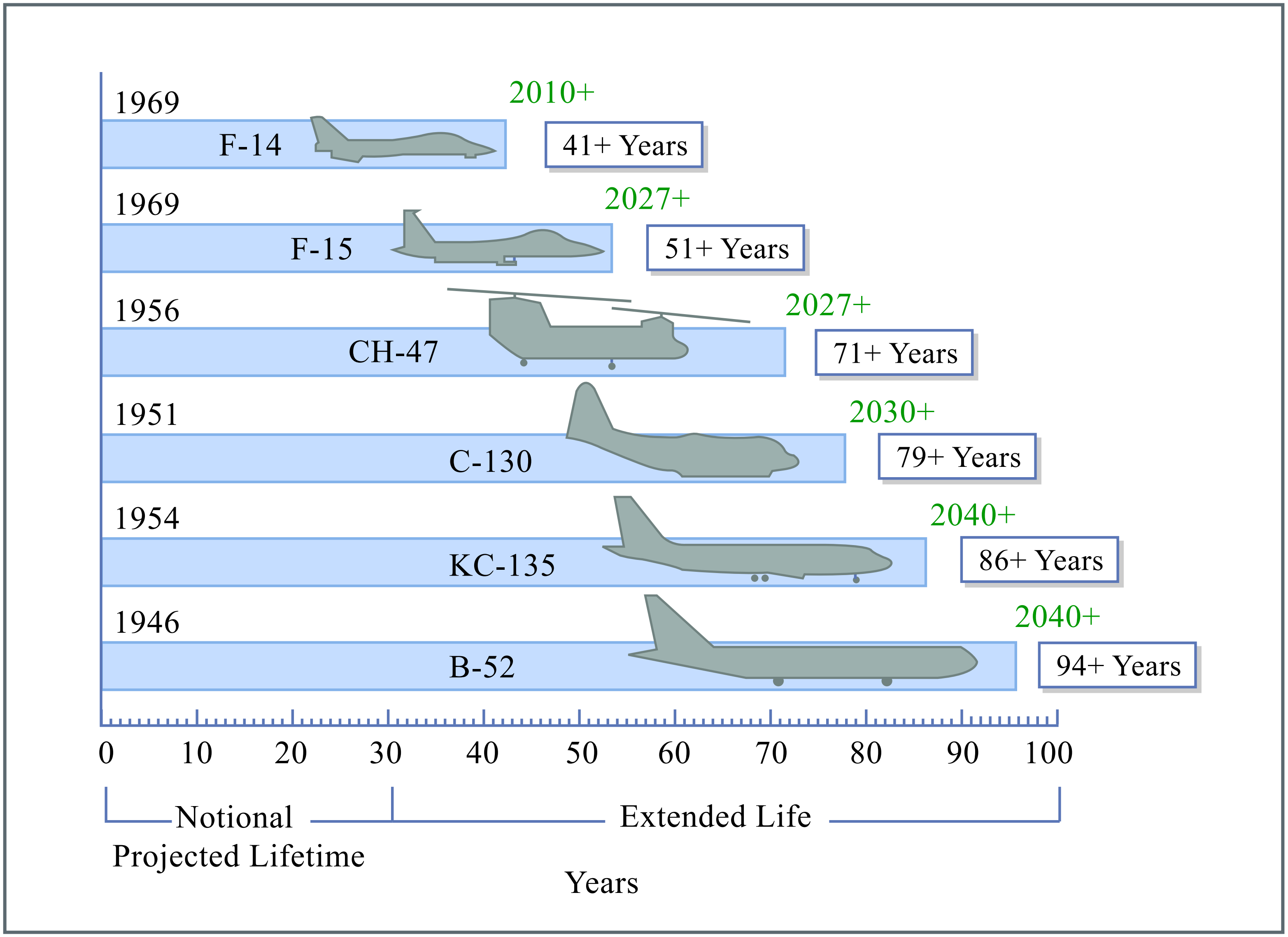

Figure by MIT OCW.

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Boeing 707 / KC-135 and Douglas DC-8

- Aircraft designed and produced in the late 1950’s / 1960’s still productive:

  .KC-135 Tankers refueling fighter aircraft in Afghanistan

  . DC-8 Freighters are still flying for UPS, Emory Airfreight and others

Aircraft Service Life Longer than Ships?

Rugged Structure:

Comprehensive fatigue analysis and testing (2 to 3 lifetimes)

- Conservative design philosophy for safety
- Progressive depot maintenance rigidly enforced (A-checks, B-checks, C-checks, D-checks)
- Designed for ease of inspection

- EXPENSIVE ASSET NEEDS LONG ECONOMIC LIFE !

ENGINES

- Designed for high reliability and low in-flight shut-down rate (e.g. 2 engine ETOPS 777)
- PDM- significant overhaul schedule, but at extended on-wing operational periods (TBO-16,000 to 20,000 hrs.)
- Extensive bench, ground and flight testing in development to weed-out premature failures and assure component / sub-system reliability

QUESTIONS ????

- How many of you have driven in a car that has been repainted?
- How many of you have driven in a car that had an overhauled engine?
- FACT: Engines of large 40’-50’ Trailer Trucks are completely overhauled every 250,000-300,000 miles

IF THE DESIGN PHILOSOPHY IS RIGHT, WE CAN EXTEND THE ECONOMIC LIFE OF COMPLEX SYSTEMS

AVIONICS

- AIRFRAME LIFE can last through several generations of avionics / software:

  C-130A (1954) Analog "boiler gauges"for cockpit displays

  C-130 (late 1980's) Evolution to digital avionics

  C-130 J (1999) Digital flat panel color displays, GPS, GPWS, Terrain Following radar, etc.

UPGRADES & DERIVATIVES

- The lifecycle of an aircraft is typically extended by upgrading or conversion:

Commercial	Military
727 to Combi	AH-64 to D
DC-10 to MD-10	CH-47A,B,C to D
DC-8 PAX to Freighter	B-52 to H model
747 PAX to Freighter	UH-1 to UH-1H

DERIVATIVES

Planning for "growth" in the original design:

Normally, the design staff lays-out a "family" of aircraft that permits downstream /future models in the product family.

Examples:

.Wingspan increase /Fuselage stretch

.Increased thrust engines/ better SFC

. Latest Avionics

. Alternate model types envisioned at the start: Freighter/Combi/ER/Convertible Freighter

F/A-18E/F to C/D to E/F to Electronic Warfare EF-18F

With an Extended Useful Life, What does this Infer Regarding Lifecycle Cost of an Aircraft?

- ACQUISITION COST= 1/3 Total LCC
- OPERATIONS / SUPPORT COST=2/3 LCC
- An aircraft from inception, must be designed to :
  . Have the performance to achieve spec mission
  . Be reliable and easy to maintain
  . Be cost-effective (achieve "design closure and business case closure")

HOW DO WE ACHIEVE ALL THESE CHARACTERISTICS?

- THE CURRENT ORGANIZATIONAL PHILOSOPHY IS CALLED:

“ INTEGRATED PRODUCT

AND

PROCESS DEVELOPMENT”

IPPD-Integrated Product and Process Development

- Evolution from the WW2 / Korean War "Chief Project Engineer" organization

Engineering provided Manufacturing with "the design"

Manufacturing had to interpret the drawings, develop a Manufacturing/Tooling Plan, design/fab tools, fab parts, assemble the aircraft

ENGINEERING "Throwing the design over the wall" to MANUFACTURING

- **RESULTS:**
  . Parts didn't fit; dimensional errors; omissions;
  .Significant Rework and "Re-do's"
  . Designs often were not producible with acceptable "yields"
  . Behind-schedule conditions
  . Cost over-runs

The Hunters and the Bear

- The Engineer
- Three Manufacturing personnel:

  1 Tool designer

  1 Industrial Engineer

  1 Final Assembly Manager

Integrated Product Team (IPT)

- Over the last 10 years or so, the IPT has evolved into the "preferred" organizational approach for developing, fielding and operating complex systems.

  Example:

  F/A-18E/F Engineering Development Contract:

  Ahead of schedule completion

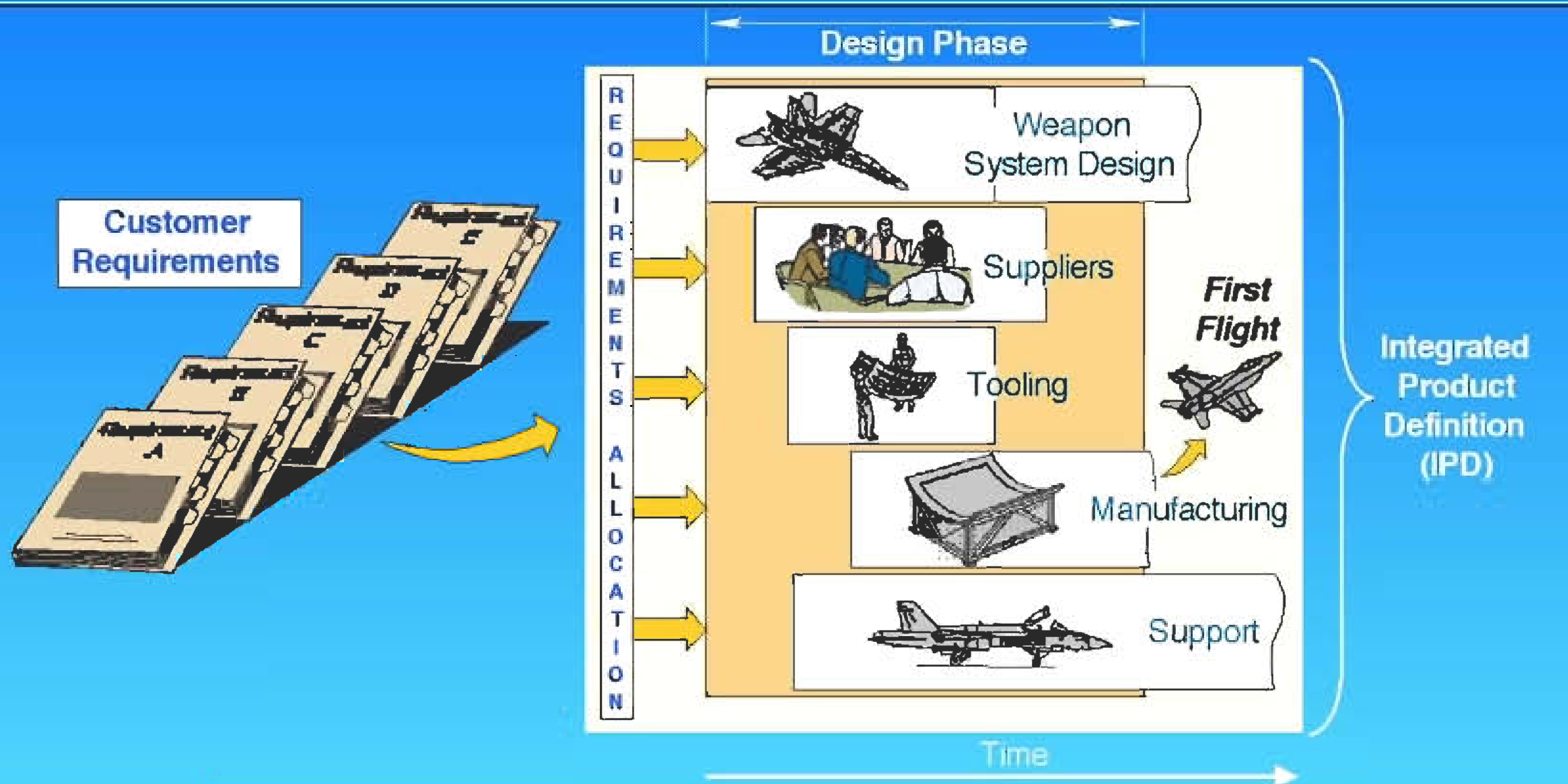
  $5 billion Budget Under-run

  1000 lbs under spec weight

The Integrated Product Development Story

F/A-18E/F

Product Development With IPD

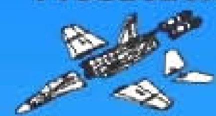


IPD Involves All Disciplines Necessary to Satisfy Product Requirements

Multi-Disciplined Product Teams in Each Business Element

Typical Team Skill Mix for Structural Components

Definition → ***Production*** → ***Support***



Product Definition Team

- Team Leader
- Planning and Control
- Systems Engineering Including DTC/LCC
- Design Engineering
- Strength Engineering
- Reliability
- Maintainability
- Subsystem Engineering
- Materials and Processes
- Producibility
- Manufacturing Engineering
- Tool Design
- Test Engineering
- Quality Assurance
- Integrated Logistics Support

Production Team

- Team Leader
- Planning and Control
- Manufacturing Engineering
- Tool Design
- Tool Fabrication
- Industrial Engineering
- Facilities Planning
- Manufacturing
- Liaison Engineering
- Process Engineering
- Production Control
- Quality Assurance
- Design Engineering
- Strength Engineering

Support Team

- Team Leader
- Planning and Control
- ILS Planning and Management
- Systems Engineering
- Technical Publications
- Package, Handle, Storage and Transport
- Retrofit Engineering
- Procurement
- Quality Assurance
- Supply Support
- Customer Support
- Material Management
- Logistics Support Analysis

Product Definition Teams

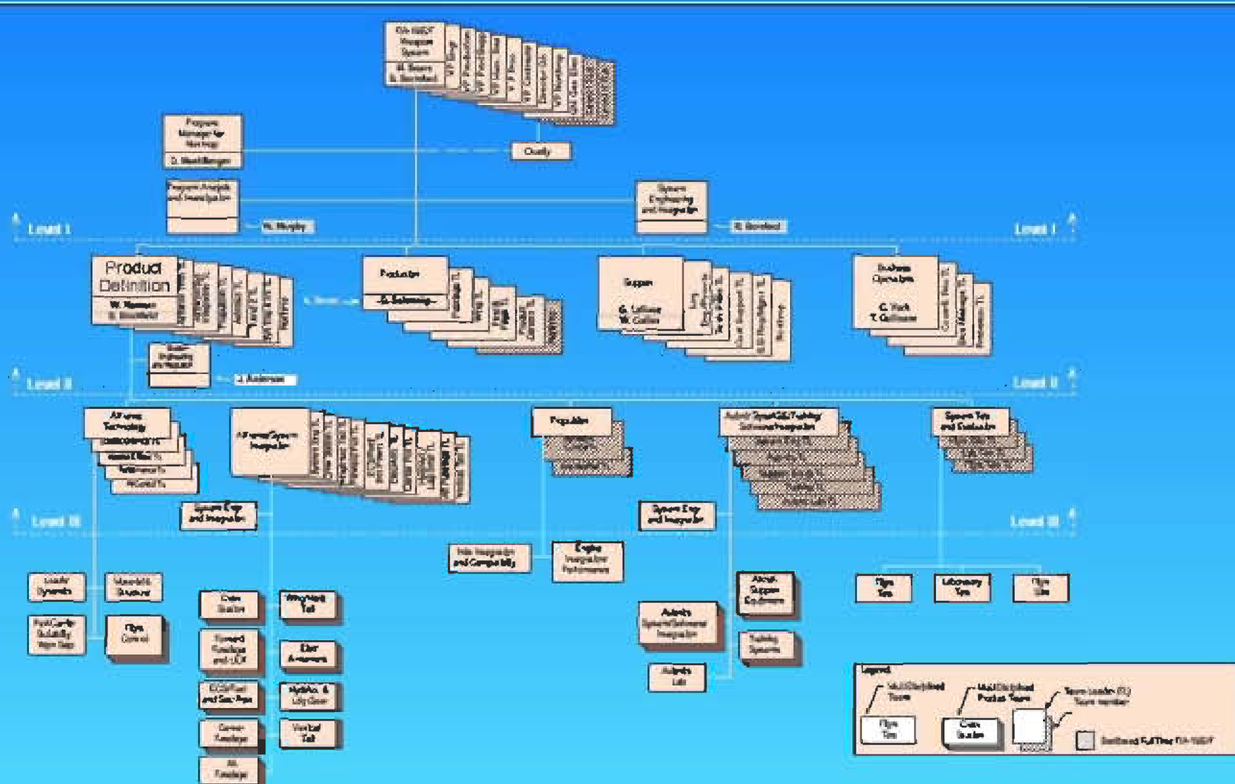
Composed of:

- Quality
- Product Support
- Procurement
- Manufacturing
- Tooling
- Engineering
- Contracts

Empowered to:

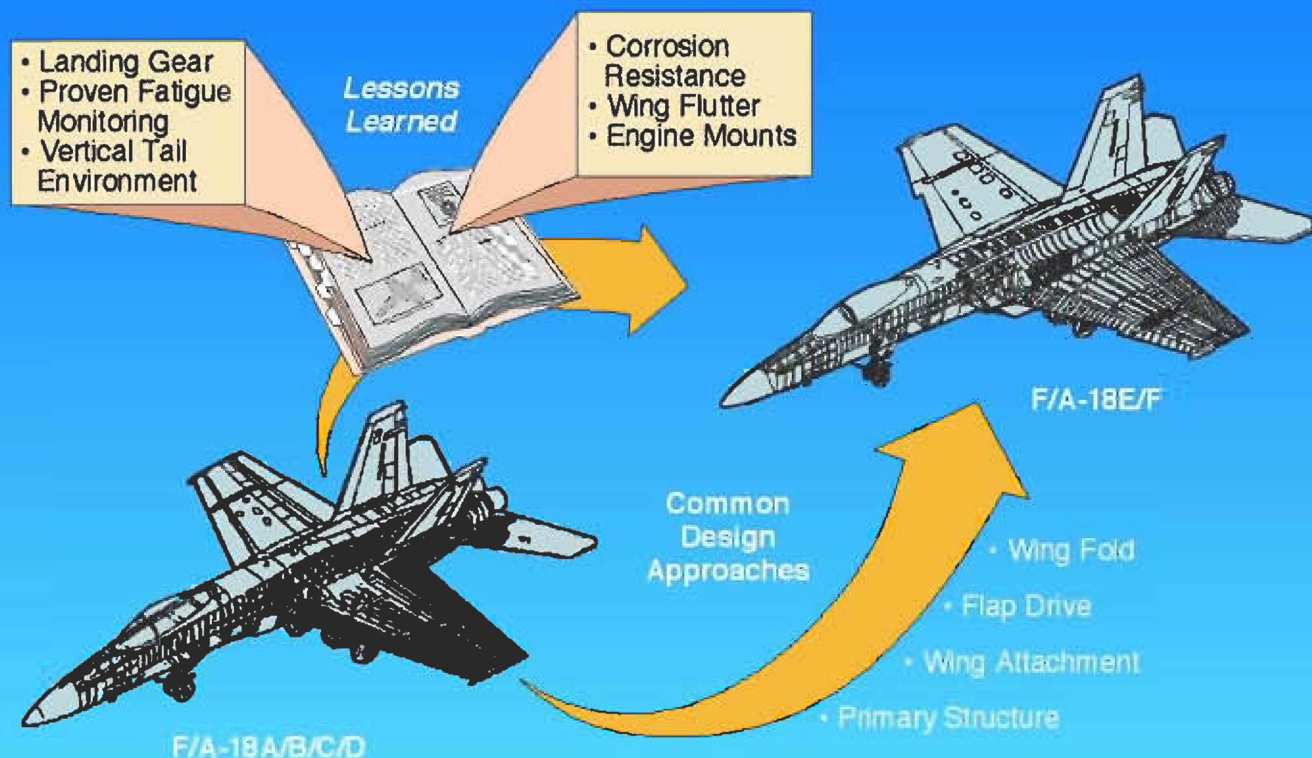
- Formulate Buy-to Package
- Establish Evaluation Criteria
- Establish Integrated Schedule
- Evaluate BTP Responses
- Recommend Supplier

Product Definition Team Organization



Our Product Definition Organization Facilitates the Flow of Requirements to the Team With Full RAA for Its Products

F/A-18A/B/C/D Experience and Lessons Learned Applied to F/A-18E/F



Improvements in Producibility Features Achieved With Concurrent Engineering Approach

The Fundamental Cost/Profit Relationship

Has changed in the last 15 years in the defense industry:

"Cost Plus" Profit Equals Price

Customer-Determined Price (Industry Must Lower Costs To Achieve Profit!)

$50,000 Ford Taurus?

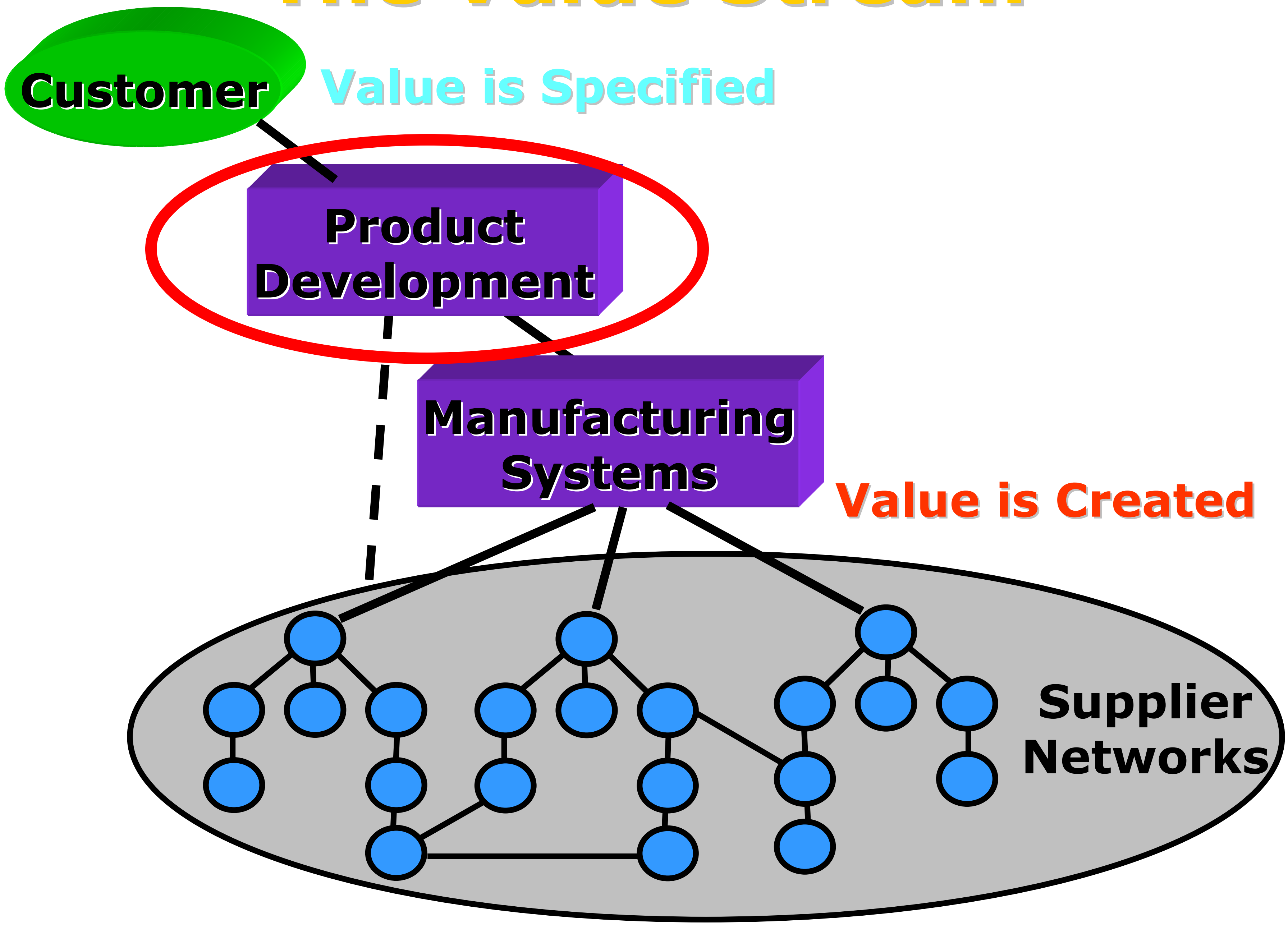
(I don't think so!)

Lean Enterprise Value Stream

To Achieve a Lean Enterprise Program, We Need to Understand a New Product's Value Stream:

1. **The Customer Specifies Value**
2. **Product Development/Engineering Create a Design Concept that Attempts to Meet Our Customer's Requirements**
3. **Suppliers Create 60 – 70% of Our Product's value (Cost)**

The Value Stream



Design to Cost Program

- A Tool to Control Cost During Define Stage
- Monitors Performance Trends
- Enables Optimization of Program Objectives
- DTC Goals Allocated to the Level V Teams
- Detailed Studies Roll-Up Into Projected Unit Cost
- Team level Cost/Performance Trade Offs
- Identify Alternative Solutions to C/D Cost Drivers

Design for Assembly (DFA)

- Focus on Part Count Reduction
  - Fewer Parts to Inventory, Plan, Tool, Produce and Assemble

Critical Questions:

Do Parts Move Relative to Each Other?

Do They Need to Be of Different Material?

Do They Need to Be Removable?

No? Then Consider Combining Parts.

Eliminate Unnecessary Parts

Variability Reduction Initiatives

- Design for Assembly
- IPD Data Sheets
- Geometric Dimensioning and Tolerancing
- Process Capabilities
- Variation Simulation Analysis
- Design for Manufacturability
- Key Characteristics

Variability Reduction Program Seeks to Enhance Compatibility Between Product Design and Manufacturing Processes

Airframe Affordability Initiatives During EMD

Design
- IPD
- Design-to-Cost
- Variability Reduction Tools

Producibility Designed-In

Tooling
- Reduced Number of Tools
- Tooling Flexibility
- Fewer Assembly Steps

Shorter Cycles/Fewer Hours

Compatibility With Manufacturing Process

Assembly
- Fewer Assembly Steps
- Fewer Parts and Fasteners
- Designs and Tooling Coordinated

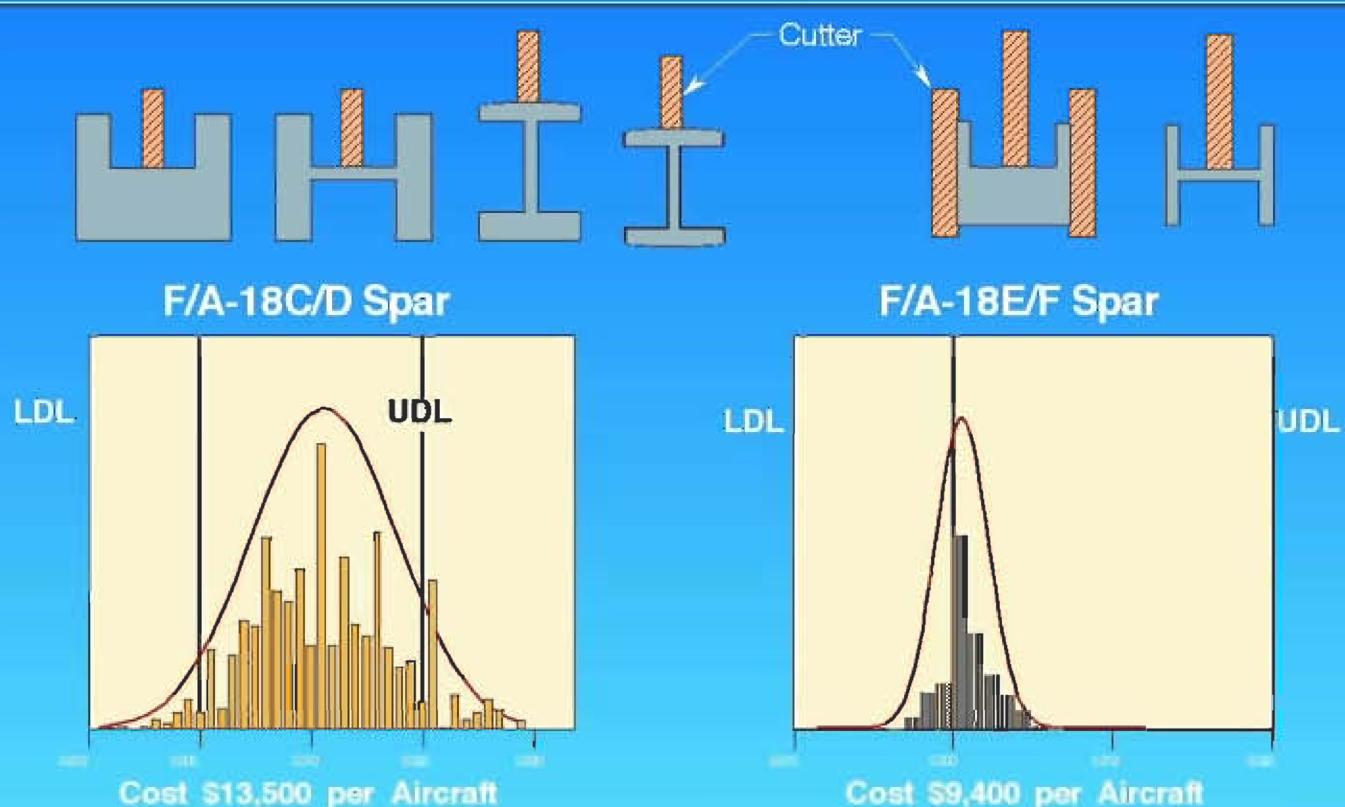
Better Fit... Reduced Scrap and Rework

Fabrication
- High Speed Machining
- Proven Composite Designs
- Reduced Cycle Time and Tooling for Machined Parts

Shorter Cycles/Fewer Hours

Our Affordability Emphasis Includes Design, Fabrication, and Assembly

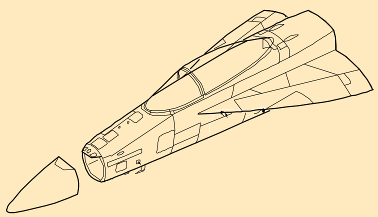
Process Capability Improvement
Bottom vs Side of Cutter



Compatibility of Processes and Designs Improves Quality and Cost

Design for Manufacturing Has Reduced F/A-18E/F Parts Count

Forward Fuselage and Equipment



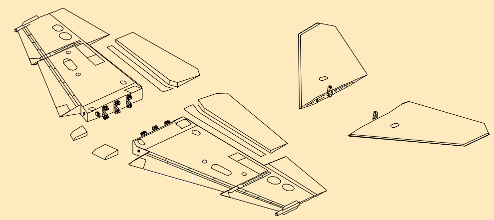
C/D Parts
5,907

E/F Parts
4,046

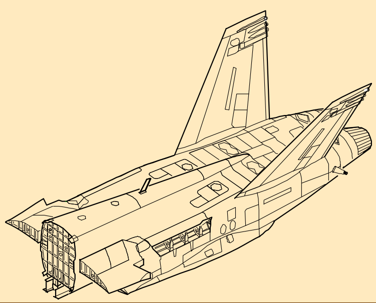
Wings and Horizontal Tails

C/D Parts
1,774

E/F Parts
1,268

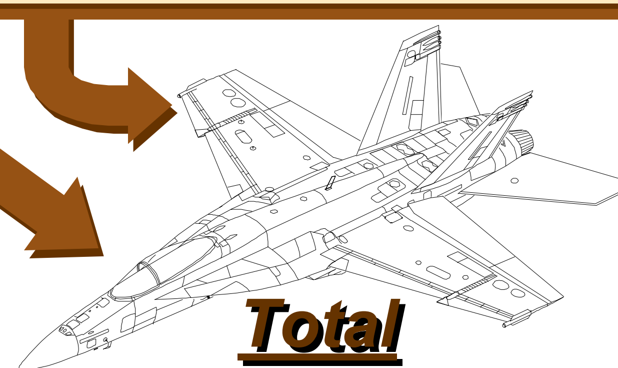


Center/Aft Fuselage, Vertical Tails and Systems



C/D Parts
5,500

E/F Parts
3,494



Total

C/D Parts	E/F Parts
14,104	8,099

E/F 25% Larger and 42% Fewer Parts Than C/D

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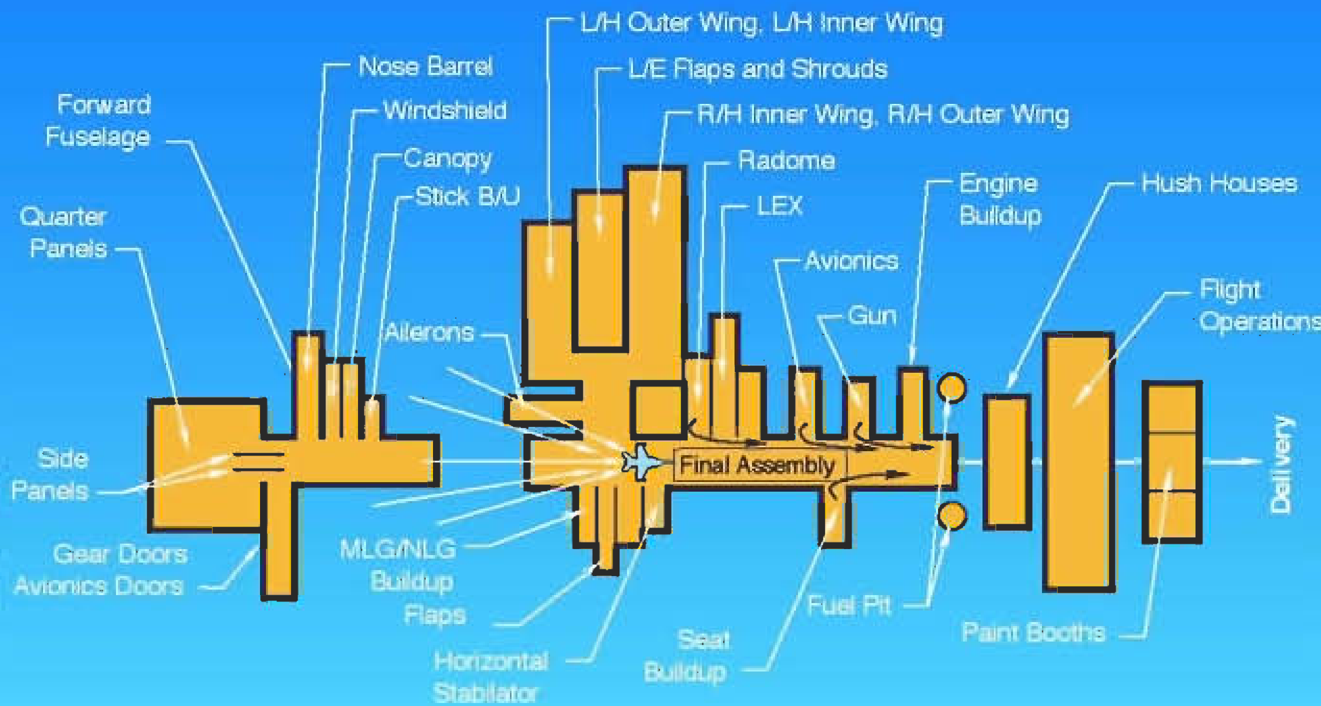
F/A-18E/F Aileron Spar

	F/A-18C/D Sheet Metal Build-Up	F/A-18E/F High Speed Machining
Detail Parts	12	1
Detail Tools	15	2
Design and Fabrication hours (tools)	158	40
Fabrication (hr)	7.3	5.8
Assembly (hr)	5.7	0
Weight (lb)	4.7	3.48

High Speed Machining Reduces the Fabrication and Assembly Hours

Assembly Continuous Production Flow Line



Continuous Product Flow Maximizes Communication Between Customers and Suppliers and Minimizes Material Handling

DESIGN

FOR

SUPPORTABILITY

DESIGN FOR SUPPORTABILITY

OR

How can we design to achieve:

Airline Dispatch Reliability

Or

Military Squadron Availability

Or

"Mission Capable Rate"

SUPPORTABILITY

- Deals with the Operation and Maintenance of the aircraft:

  . Reliability

  . Maintainability

  . Human Factors Engineering

  .Safety Engineering

RELIABILITY

- SYSTEM RELIABILITY-

  Airline Dispatch Reliability- the ability of an aircraft to depart the gate within 15 mins. of scheduled departure time unrestrained by mechanical, electrical or software issues.

  (99.5% is a current demand)

RELIABILITY(cont'd.)

- COMPONENT RELIABILITY-

  Typically measured as :

  MEAN TIME BETWEEN FAILURE (MTBF):

Helicopter transmission	3000 hours
Rotor Blade	4000 hours
Flight Control Computer	2500 hours

HUMAN FACTORS ENGINEERING

- Design of the aircraft to ensure that it can be operated and maintained efficiently and safely.

  Examples:

.Ability of a mechanic to lift a 40lb.battery

.”Fool-proofing” a design to eliminate the possibility of inadvertently crossing electrical wires

.Ensuring Caution / Warning displays are readable

MAINTENANCE ENGINEERING

- (ALSO KNOWN AS MAINTAINABILITY ENGINEERING)
- EXAMPLES:

  .Accessability of key components for ease of removal

  .Ilustrated Maintenance Manuals using photos, 3D drawings, for disassembly/ assembly

  . Required maintenance /lubrication schedules, TBOs,

  . Indentured Parts Lists

  .Designing for Autonomic Maintenance down-loading from enroute aircraft

Managing the Design Process
(Lots of Issues to Keep Track of !!!!)

- Requires an extensive /Iterative Tracking System with monthly specialist estimates:

Performance- weight, range, payload, time-to-climb, etc.

Design to Unit Production Cost

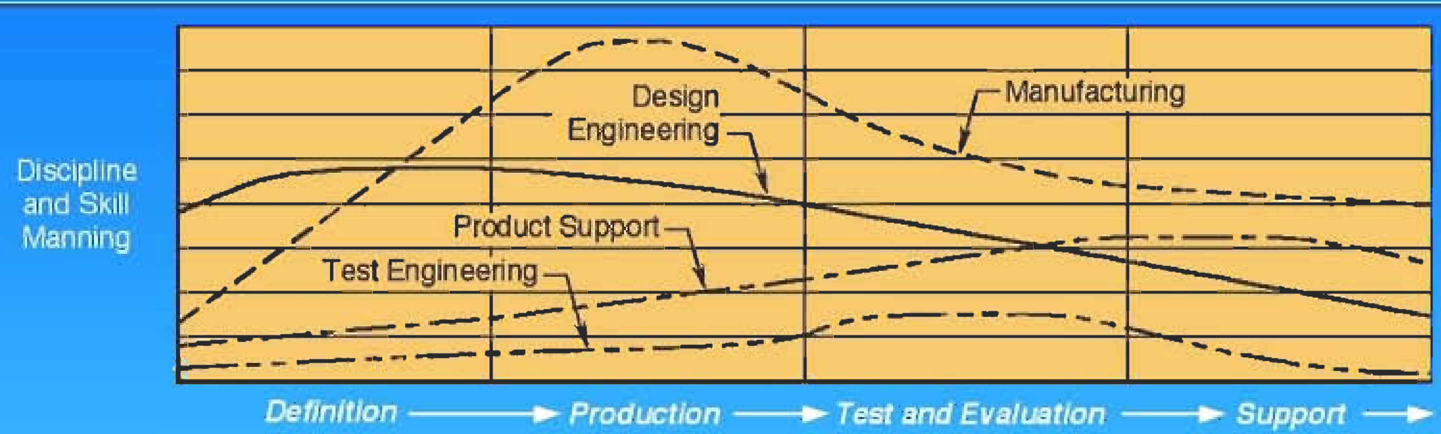
Reliabilty

Maintainability

Schedule

Cost / Earned Value

Air Vehicle IPD/CE Process Model



Product Definition Teams	Production Teams	Test Teams	Support Teams
Production Team; Support Team; Test Team	Product Definition Teams; Support Team; Test Team	Product Definition Teams; Support Team; Production Team	Production Team; Product Definition Team

Composition of Product Teams Change Over the Life of the Program, in Terms of Number, Skills and Disciplines, as Well as Their Leadership in the Process.

MCDONNELL DOUGLAS AEROSPACE

The SUPPLY CHAIN

60-70% OF A TOTAL AIRCRAFT
IS TYPICALLY PROVIDED BY
KEY SUPPLIERS:

Fuselage Sections

Wing / Empennage

Avionics/ FCC/ Com-Nav

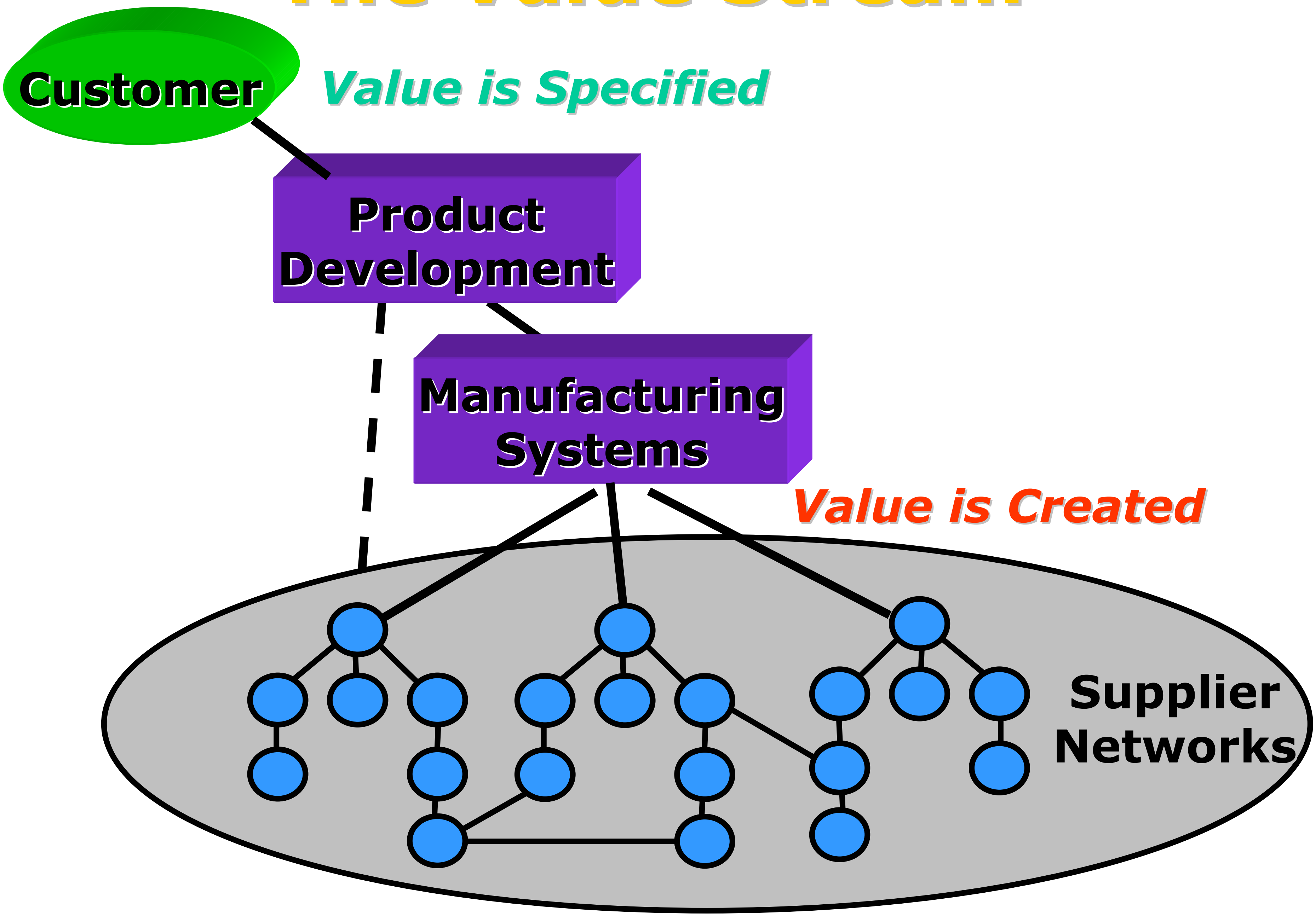
Flight Control Surfaces

Actuators, Hydraulic valves

Engines, APU

Electrical Generators, ECS, etc.

The Value Stream



TO ACHIEVE THE MISSION SPECIFICATION

- OVERALL TECHNICAL PARAMETERS ARE APPORTIONED TO EACH SUBCONTRACTOR, e.g.:

Parker Aerospace (Hydraulic Flap Actuator Supplier) would receive a “Procurement Specification” stating the requirements for:

.Allowable space envelope, weight, reliability, MM/FH, Qual requirements, , unit cost, delivery date, etc.

FLOWDOWN

- THE PROCESS OF DRIVING ALL ELEMENTS OF THE TECHNICAL SPECIFICATION AND BUSINESS AGREEMENT TO ALL SUPPLIERS IS KNOWN AS:

"SPECIFICATION FLOWDOWN"

SUPPLY CHAIN

- WITHIN THE IPT, THE MATERIAL DEPT./ SUPPLIER MANAGEMENT ORG./ SUPPLY CHAIN MGT. ORG'N. WILL:
  - .Identify Capable Suppliers
  - .Conduct a Competitive Procurement
  - .Negotiate Technical Spec, Price, On-Dock date
  - .Negotiate Technical Changes
  - .Closely Monitor Progress vs. Plan

LIFECYCLE MANAGEMENT SUMMARY

- INTRICATE PROCESS!
- MILLIONS OF DATA BITS TO MANAGE OVER 40+ YRS.
- HUGE AMOUNT OF DETAIL DECISIONS TO TRACK / MONITOR COMPLIANCE
- INTEGRATED PRODUCT TEAM HAS THE RIGHT INGREDIENTS TO MAKE IT HAPPEN!

LESSONS LEARNED

- Early and constant attention to tracking schedule, cost, technical performance and configuration are key to achieving program objectives.
- "Earned Value" method of schedule / cost tracking is superior (BCWS, BCWP, ACWP)
- Close coordination with Customers, Suppliers in an atmosphere of "open and honest" communication is key

LESSONS LEARNED (Cont'd.)

- IPT TEAM FOCUS ON THE PRODUCT THROUGHOUT THE LIFECYCLE IS CRITICAL:
  - . Team decisions should be based on

"WHAT'S BEST FOR THE PRODUCT!"

FORMULA FOR SUCCESS!!!

HOMEWORK ASSIGNMENT

- 1.For your respective aircraft, go into "Jane's All The World's Aircraft" or other sources and enter into your spreadsheet:

  a.All the derivative / upgrade models and their distinguishing characteristics(more thrust, payload, range, new avionics, new weapons, etc.)

  b. List the first flight date and calculate the number of years the basic aircraft has been in operation

Reference

- 2002 Minta Martin Lecture, April 19, 2002

  "Lean Engineering (or Why we no longer can ignore 80% of a Product's Cost!)"

  Prof. Allen Haggerty, Hunsaker Visiting Professor, Dept. of Aeronautics & Astronautics, MIT